

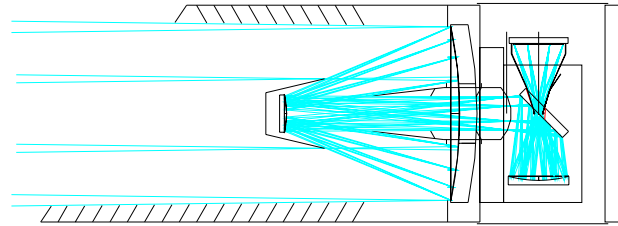
Supernova Acceleration Probe (SNAP) Stray Light Overview

15 March 2005

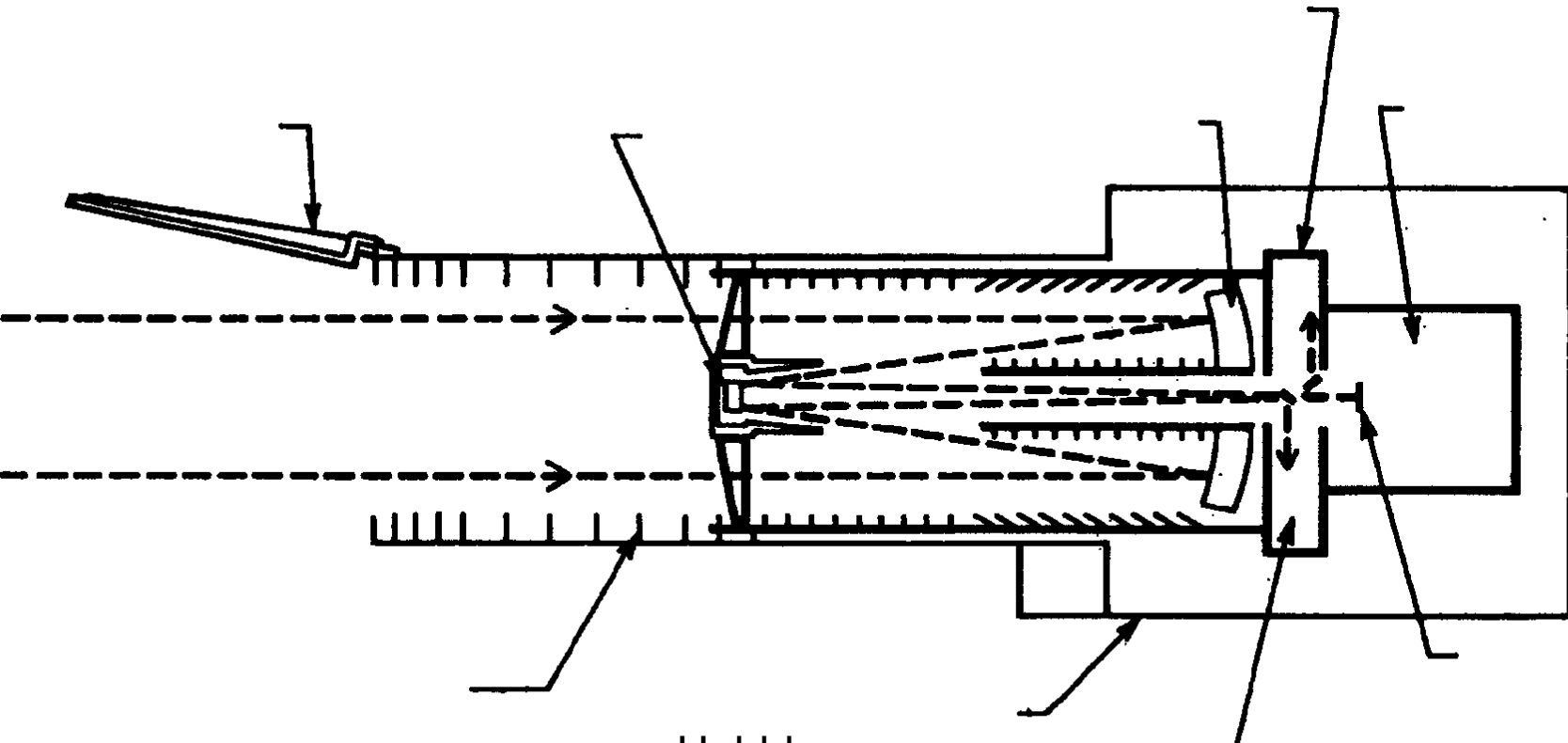
Michael Sholl

- SNAP Telescope noise floor is in-field Zodiacal radiation
- Goal of stray light design: stray-light \ll Zodi
- In dark Ecliptic polar survey regions, this is $\sim 23^{\text{rd}}$ magnitude per square arcsec
- In L2 halo orbit, Earth and Moon occasionally illuminate interior of stray light baffle
- Earth: maximum equivalent magnitude: 6 (ref. Jelinsky scattering sources) or $4.4\text{e}8 \text{ ph/s/m}^2$
- Moon: maximum equivalent magnitude: 11 ($4.4\text{e}6 \text{ ph/s/m}^2$)
- Starlight is roughly of the same order as Zodiacal radiation
- Excursions into lower Ecliptic latitudes increases Zodiacal radiation dramatically (all-sky survey)

Current Baseline



SNAP baseline



Zodiacal radiation at focal plane



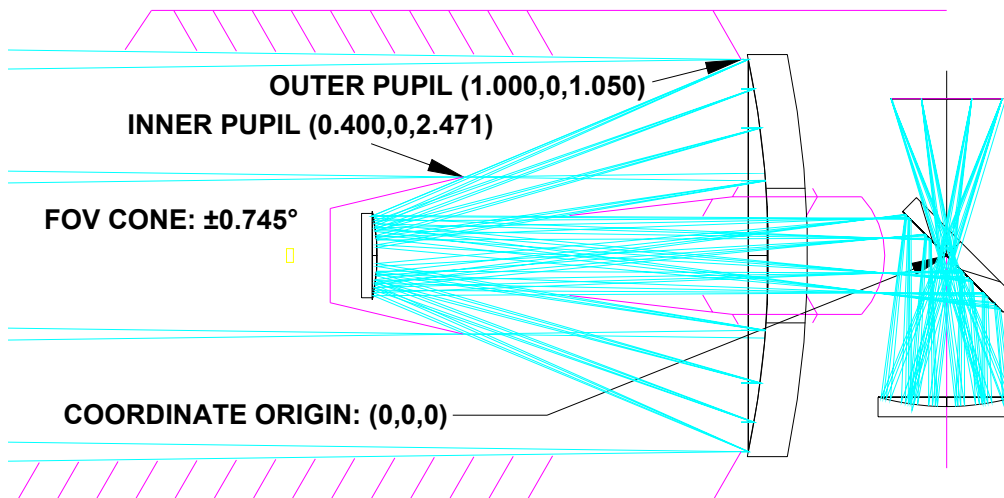
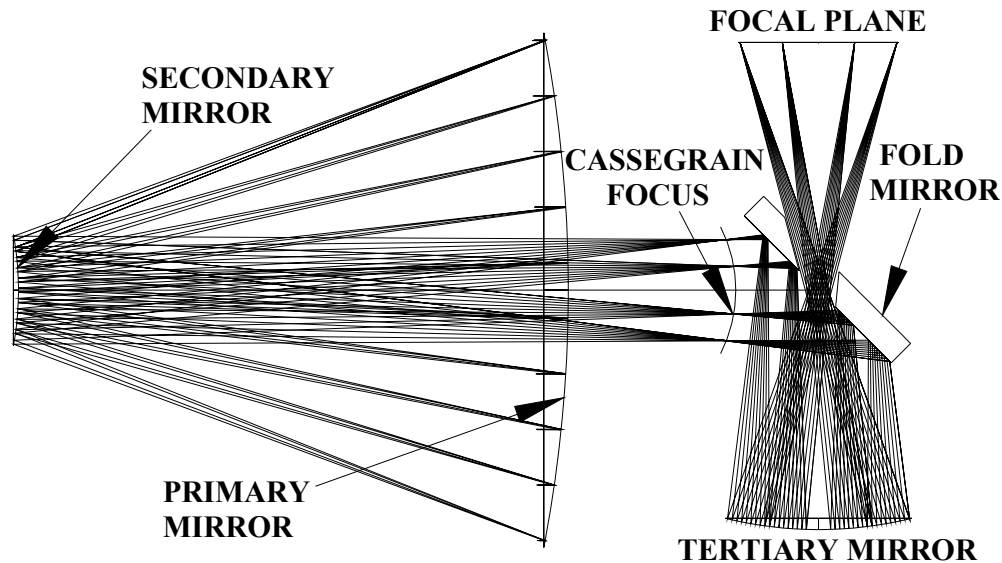
- HgCdTe pixels (infrared) are 18 μ m (linear)
- CCD pixels are 10.5 μ m (linear)
- Quantum efficiency of silicon and HgCdTe not considered (effects signal and noise equivalently)

		CCD (10.5 μ m pixels)						HgCdTe (18 μ m pixels)		
Filter		0	1	2	3	4	5	6	7	8
λ central	nm	470	541	622	715	822	945	1087	1250	1438
λ low	nm	390	449	516	593	682	784	902	1037	1193
λ high	nm	550	633	727	836	962	1106	1272	1463	1682
Bandwidth	nm	160	184	212	243	280	322	370	426	489
$\Delta\lambda$ 65% scaled	nm	104	120	138	158	182	209	241	277	318
Zodiacal Light (photons/s) thru filters, on detector face (QE not considered)										
		0.127	0.168	0.218	0.247	0.273	0.293	0.898	0.902	0.871
Irradiance of zero magnitude star in filter band (photons/m ² /s/ μ m)										
		1.3E+11	1.0E+11	8.0E+10	6.0E+10	5.0E+10	3.3E+10	2.8E+10	2.0E+10	1.5E+10

Strategy for stray light design

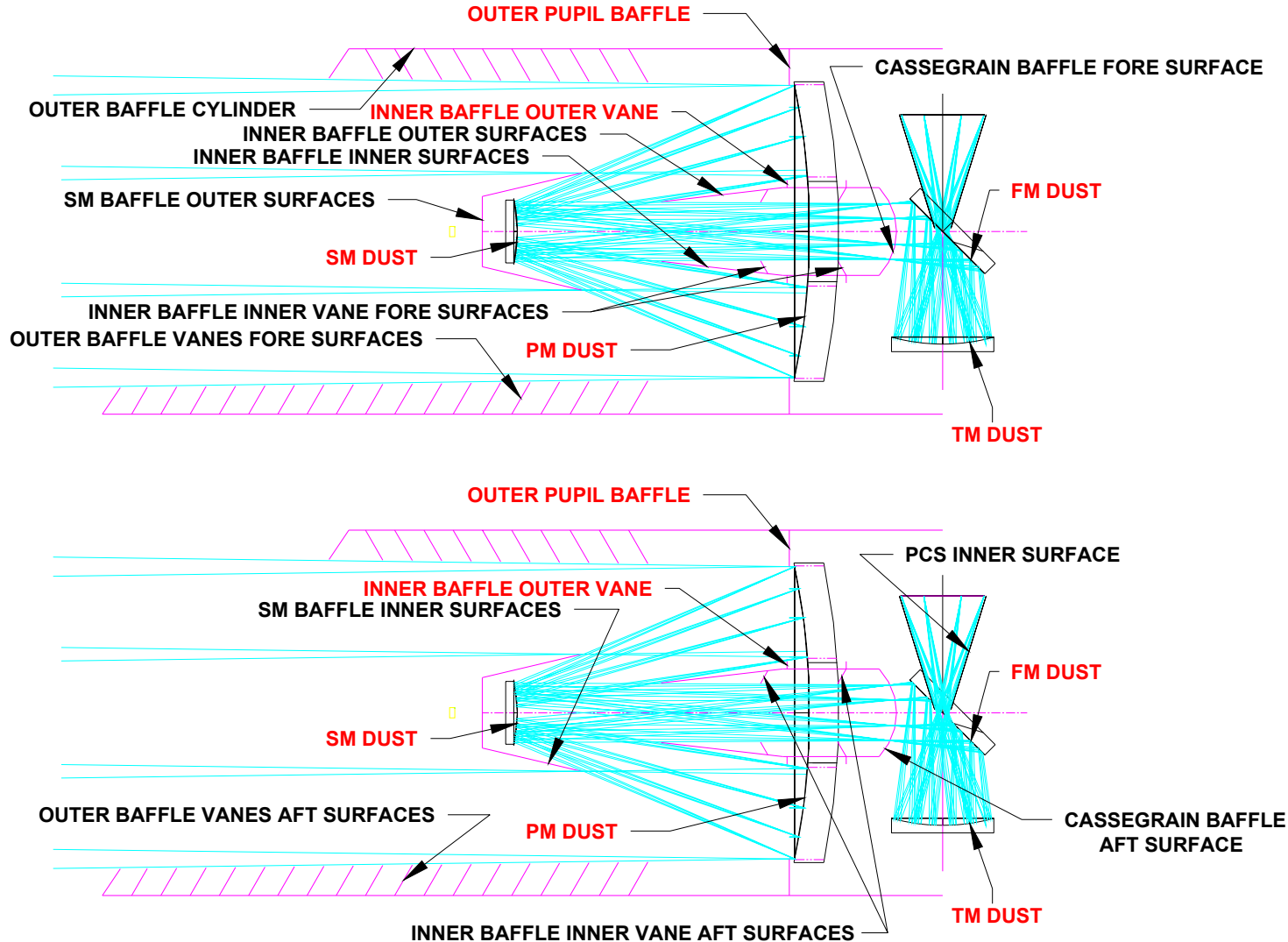


- **Eliminate first-order stray light paths**
 - Identify illuminated and visible surfaces
 - Per. BRO recommendations: move or block
- **Cold (140K) stop extends from focal plane to internal image of telescope pupil**
 - Eliminates majority of thermal load from room-temperature optics
 - As will be shown, emission from mirrors is main source, but within requirements
- **Cassegrain baffle has cutouts for detectors (remainder of focal plane is dark)**
- **Dust is the main first-order straylight path by which external stray light enters TMA65**
 - Goal: Level 300 surfaces
 - Try to ensure design has margin with Level 500 surfaces
- **Baffles**
 - Sun blocked by at least 2 edges
 - Use durable coatings where possible
 - Anodized surfaces
 - Aeroglaze paint
 - Avoid exotic, fragile coatings
 - Non-contact labyrinths on closeouts
- **Analysis techniques**
 - Back of envelope, order of magnitude analysis
 - Non-sequential raytrace (ASAP)



- TMA Design by M. Lampton
- Requirements in 00008-MW02.doc
- Internal field stop (Cassegrain focus) and iris
- Outer pupil defined by vane near PM
- Inner pupil defined by Secondary Baffle
- FOV cone $\pm 0.745^\circ$

Illuminated and Critical Surfaces

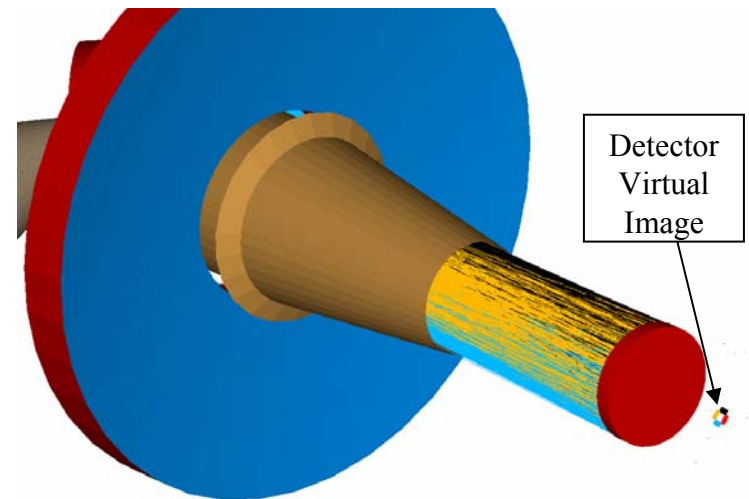
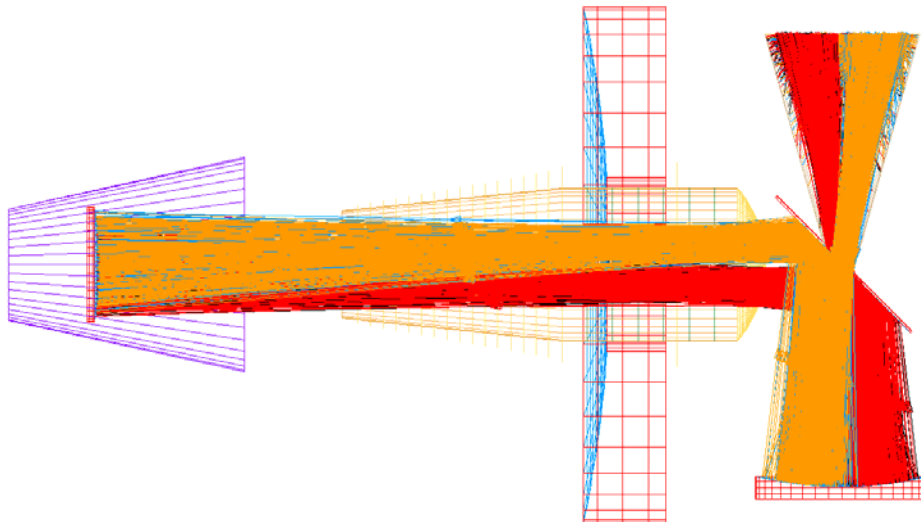


Illuminated surfaces (upper) and critical surfaces (lower). Items in red are found in both lists, and are therefore first order stray light paths

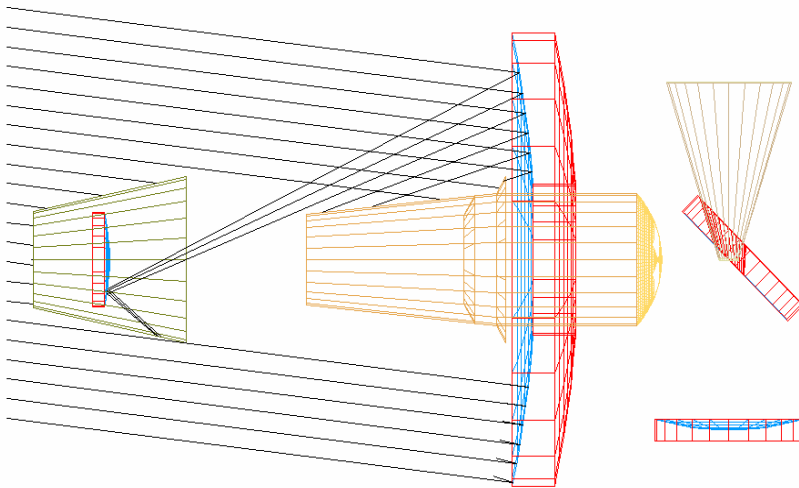
Detector Virtual Image



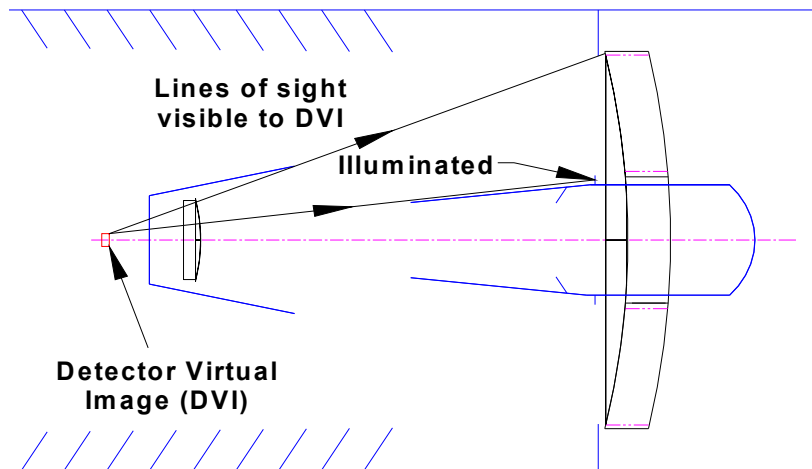
- Reverse raytrace random rays from focal plane
- Trace to SM
- Reflect direction of rays
- Find minimum focus size of resulting spot
- This is the Detector Virtual Image (DVI)
- Stray light which intercepts the SM only reaches detector if it is directed toward DVI
- Greatly reduces computational burden



Inner Baffle (Primary Baffle)

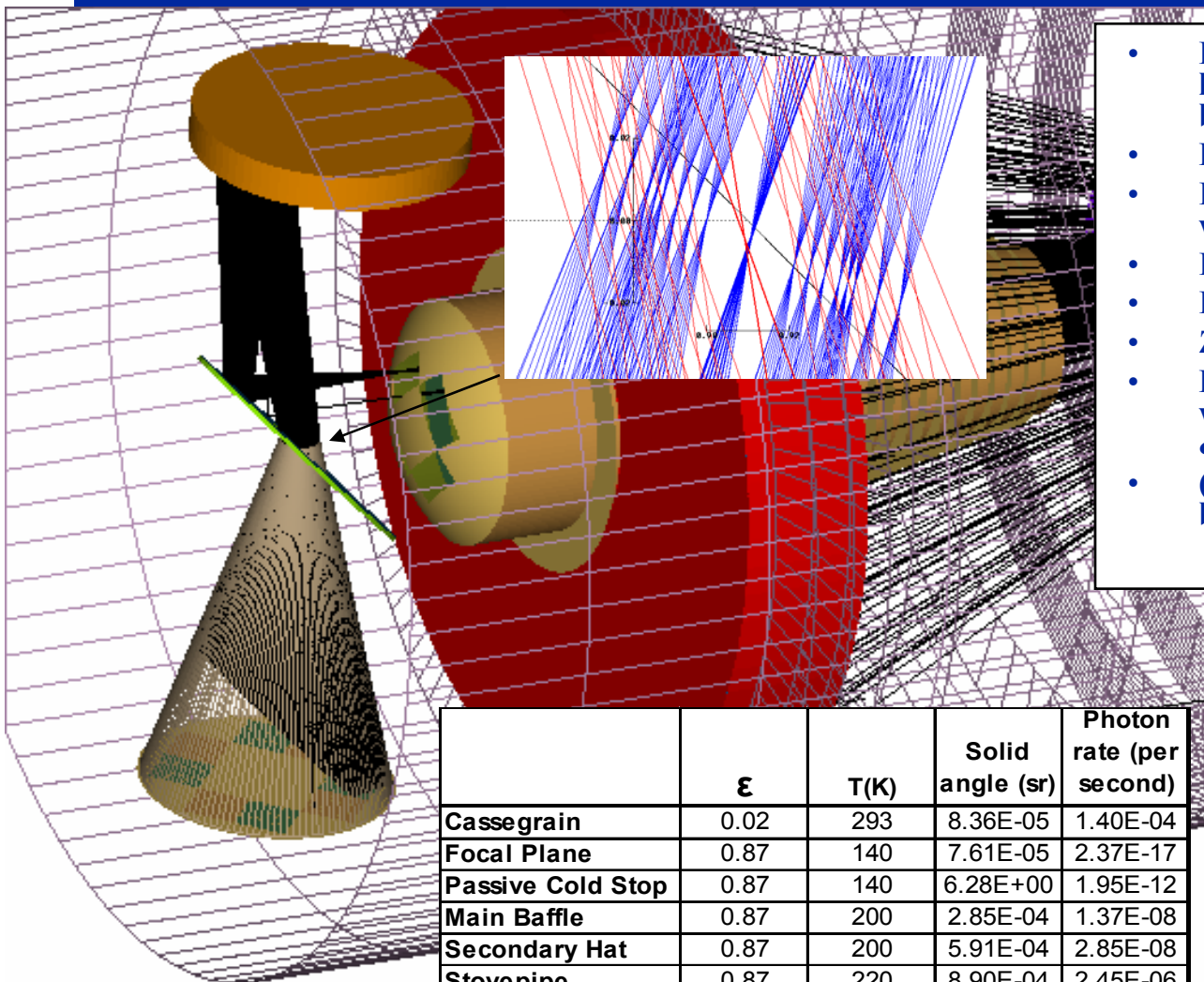


- Designed to reduce first-order stray light paths
- Outer surface is illuminated by direct and reflected, out of field light
- Outer surface made invisible to DVI by angling outward (lower figure)
- Inner vanes designed to reduce specular bounces
- Coating: Specular Black such as Aeroglaze Z302



- Filters are transmissive to $\sim 1.8\mu\text{m}$; coating BRDFs should be quantitized from $0.3\mu\text{m}$ to $1.8\mu\text{m}$.
- State of art in coatings is likely to evolve over next few years
- General findings of stray light analysis and literature search:
 - Durable coatings (anodized aluminum or Aeroglaze paint) preferred on structures subject to handling damage (outer baffle)
 - NIR tailored black coatings such as Desoto Black are preferred for diffuse surfaces
 - ASAP analyses suggest specular black paint (Z302) leads to better PSTs, in some instances, than diffuse black paints
- Suitability of selected coatings to be verified via straylight model

Internal Iris and Passive Cold Stop

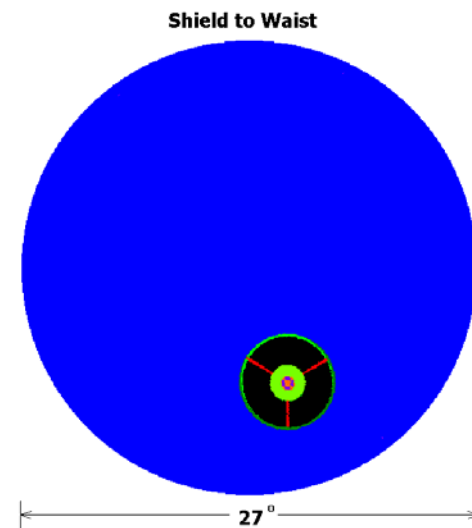


- Internal iris blocks direct scattered light from main baffle, and inner baffle
- Reverse raytrace shown
- Passive Cold Stop (PCS) extended to waist
- Pixels see PCS mainly (see Table)
- PCS at 140K
- Zodi ~ 0.3 counts/s
- Results suggest we meet requirements without internal cold pupil (SM spider & baffle) image
- (Cannot be supported without blocking good light anyway)

	ϵ	T(K)	Solid angle (sr)	Photon rate (per second)
Cassegrain	0.02	293	8.36E-05	1.40E-04
Focal Plane	0.87	140	7.61E-05	2.37E-17
Passive Cold Stop	0.87	140	6.28E+00	1.95E-12
Main Baffle	0.87	200	2.85E-04	1.37E-08
Secondary Hat	0.87	200	5.91E-04	2.85E-08
Stovepipe	0.87	220	8.90E-04	2.45E-06
Secondary Struts	0.02	293	1.54E-04	2.57E-04
Deep Space	0.04	293	5.39E-03	1.80E-02

P. Jelinsky

Total Rate 0.01842

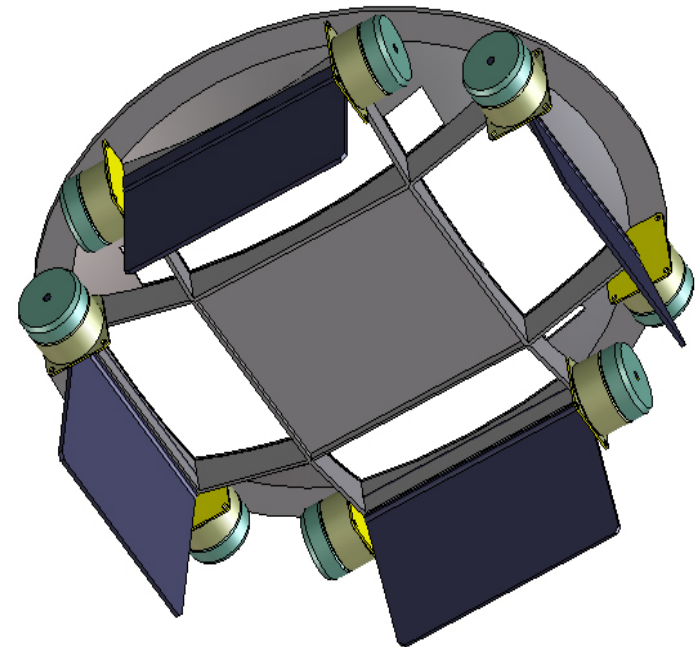
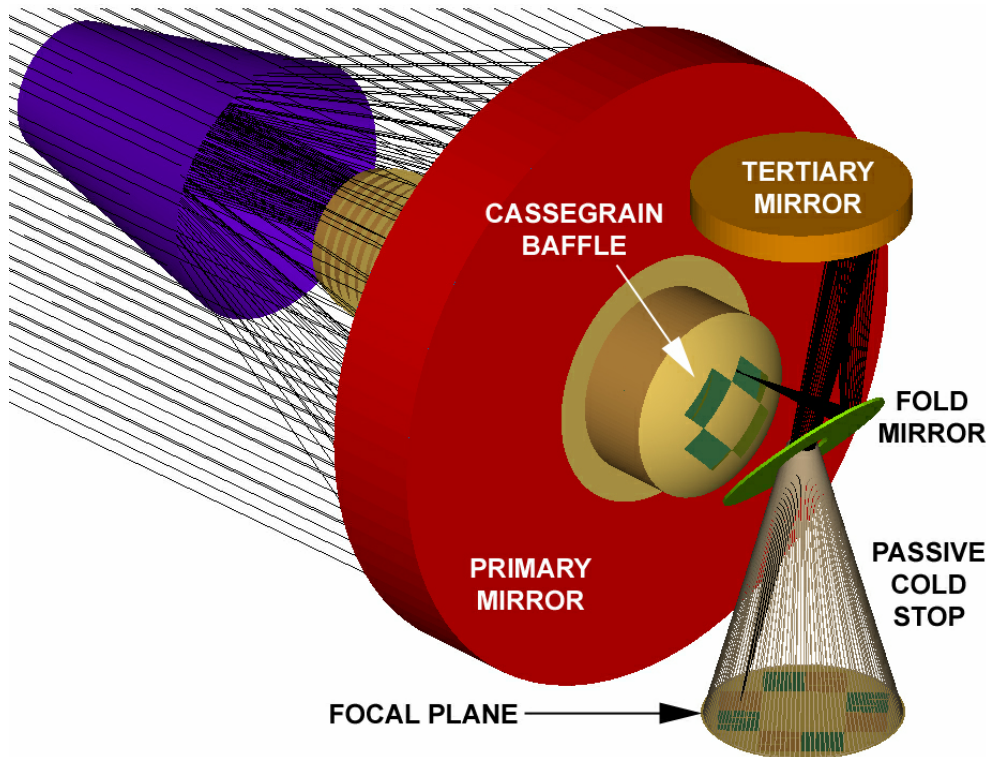


- Space
- Shield
- Focal Plane
- Secondary Baffle
- Outer Baffle
- Inner Baffle
- Cassegrain Mask
- Secondary Strut

Cassegrain Baffle & Shutter



- Cassegrain stray light baffle effectively shadows inactive areas of focal plane.
- Shutter moved from internal pupil to Cassegrain focus
 - Allows PCS to extend without interruption to internal iris
- Baffle is warm, but not visible to detector pixels



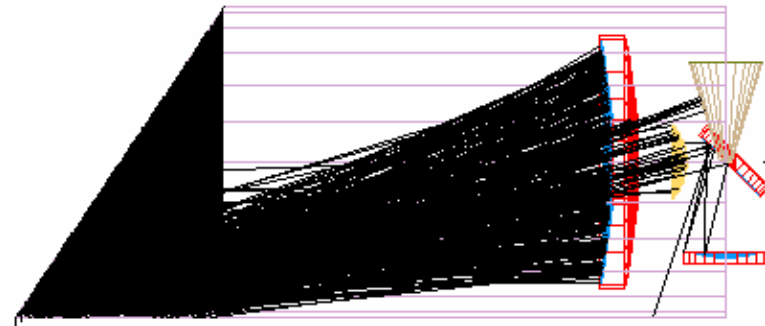
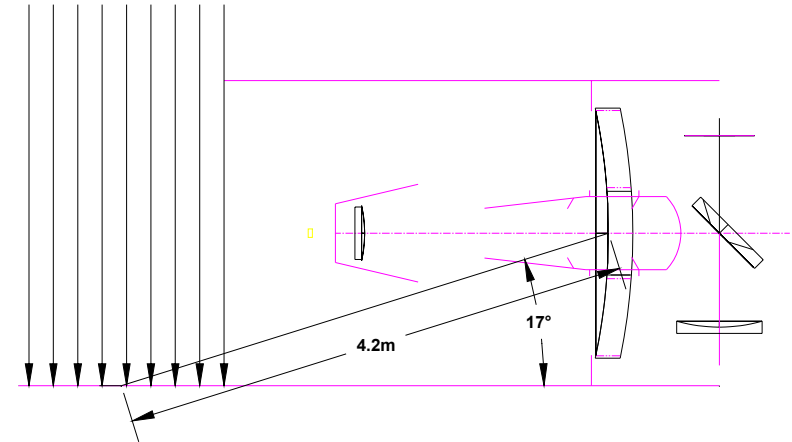
- Redundant limited angle torque motor drives
- Magnetic resolvers and feedback loop in design
- Shutters open/close in <100ms

- **Breault Research Organization product**
- **Breault involved with stray light baffle design for Hubble**
- **Non-sequential raytrace program**
- **BRDF of dusty mirrors, and scattering surfaces**
- **Compute PST (Point Source Transmittance) = irradiance on focal plane divided by irradiance at entrance pupil.**
- **Need reality check before using this, or any analysis package**

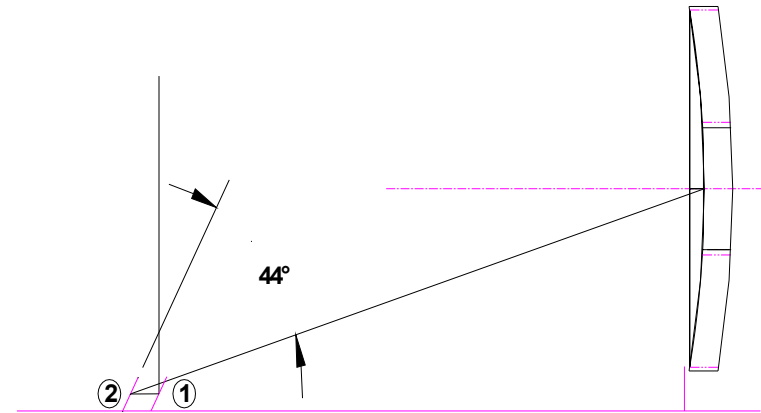
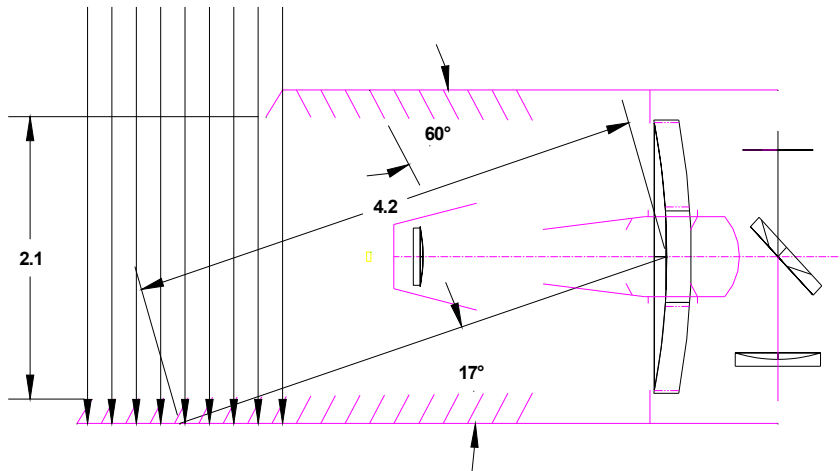
Case 1: single bounce baffle



- The value $\beta - \beta_0 = \sin(0) - \sin(73) = 0.96$, and the corresponding BRDFs are:
 - $\text{BRDF}_{\text{Z302}} = 0.001/\text{sr}$
 - $\text{BRDF}_{\text{Z306}} = 0.015/\text{sr}$
- Area of the mirror is $0.88 * \pi * 12 = 2.76 \text{ m}^2$
- The light arriving at the PM, therefore, should be:
 - $P_m = P_0 * \text{BRDF} * (2.76 * \cos(17^\circ) / 4.2^2) * \cos(73^\circ)$
 - $P_m \text{ Z302} = P_0 * 0.001 * (2.76 * \cos(17^\circ) / 4.2^2) * \cos(73^\circ) = P_0 * 4.4\text{E-}5$
 - $P_m \text{ Z306} = P_0 * 0.015 * (2.76 * \cos(17^\circ) / 4.2^2) * \cos(73^\circ) = P_0 * 6.6\text{E-}4$
- ASAP results:
 - $P_m \text{ Z302} = P_0 * 2.4\text{E-}5$
 - $P_m \text{ Z306} = P_0 * 1.4\text{E-}4$
- Conclusions: ASAP predicts low by a factor of 2-3



Case 2: Bercovitz Baffle



Bounce	$\beta - \beta_0$	Θ_0	$BRDF_{Z302}$	$BRDF_{Z306}$
1	0.37	60°	0.0013	0.025
2	0.22	30°	0.0030	0.018

The view factor of baffle vane 2 to vane 1 is 0.2 (roughly 20% of what is seen by baffle 1 is baffle 2). The power arriving at the back of baffle 2 therefore is:

$$PB2 = P0 * BRDF * (2\pi * 0.2) * \cos(30^\circ)$$

$$PB2Z302 = P0 * 0.0014$$

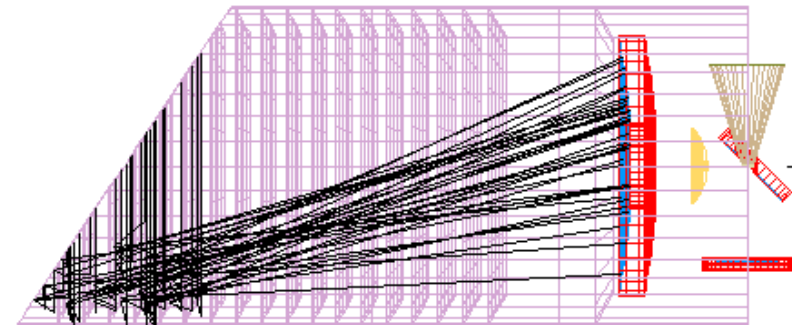
$$PB2Z306 = P0 * 0.027$$

The illuminated areas, as seen by the PM, are the back surfaces of the 2 baffles. The light reaching the PM may be approximated:

$$PM = PB2 * BRDF * (2.76 * \cos(17^\circ) / 4.2^2) * \cos(73^\circ)$$

$$PMZ302 = P0 * (0.0014) * (1.3E-4) = P0 * 1.8E-7$$

$$PMZ306 = P0 * (0.027) * (1.3E-4) = P0 * 3.5E-6$$



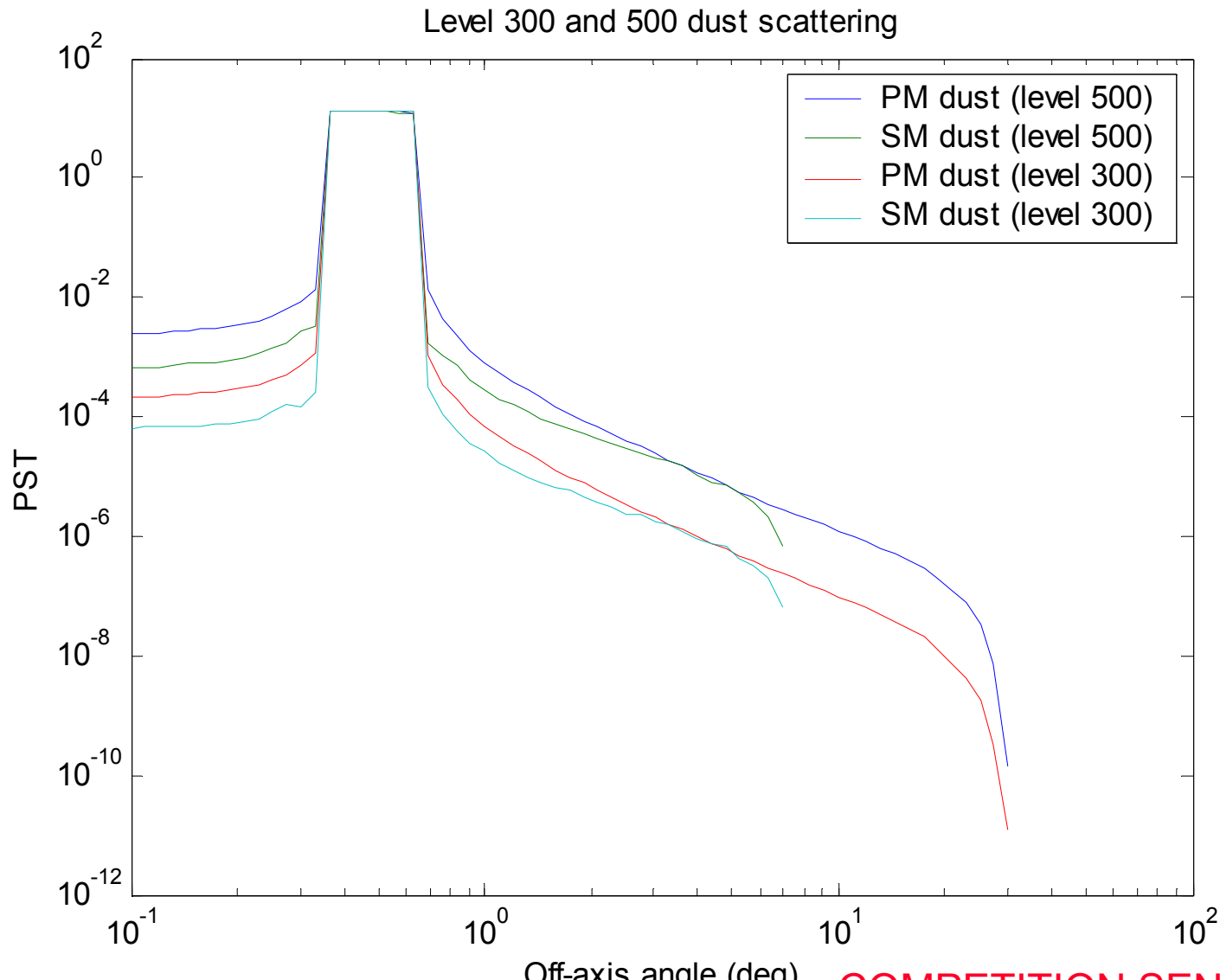
ASAP Results

$$PMZ302 = P0 * 4E-8$$

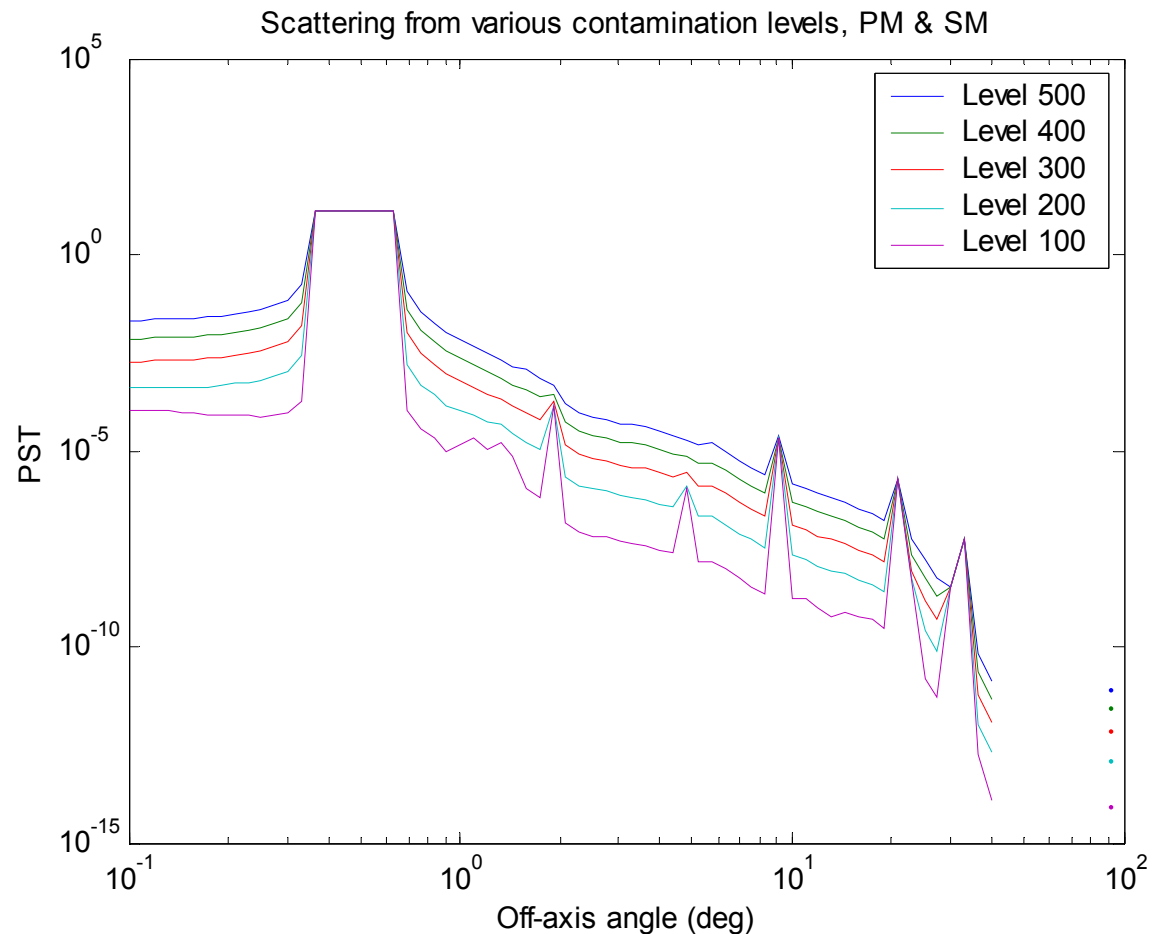
$$PMZ306 = P0 * 2.8E-6$$

Conclusion: ASAP predicts low by factor of 2-3

- Directly viewed sky, scattered from mirrors into optical path
- Contributions of TM and FM were very low



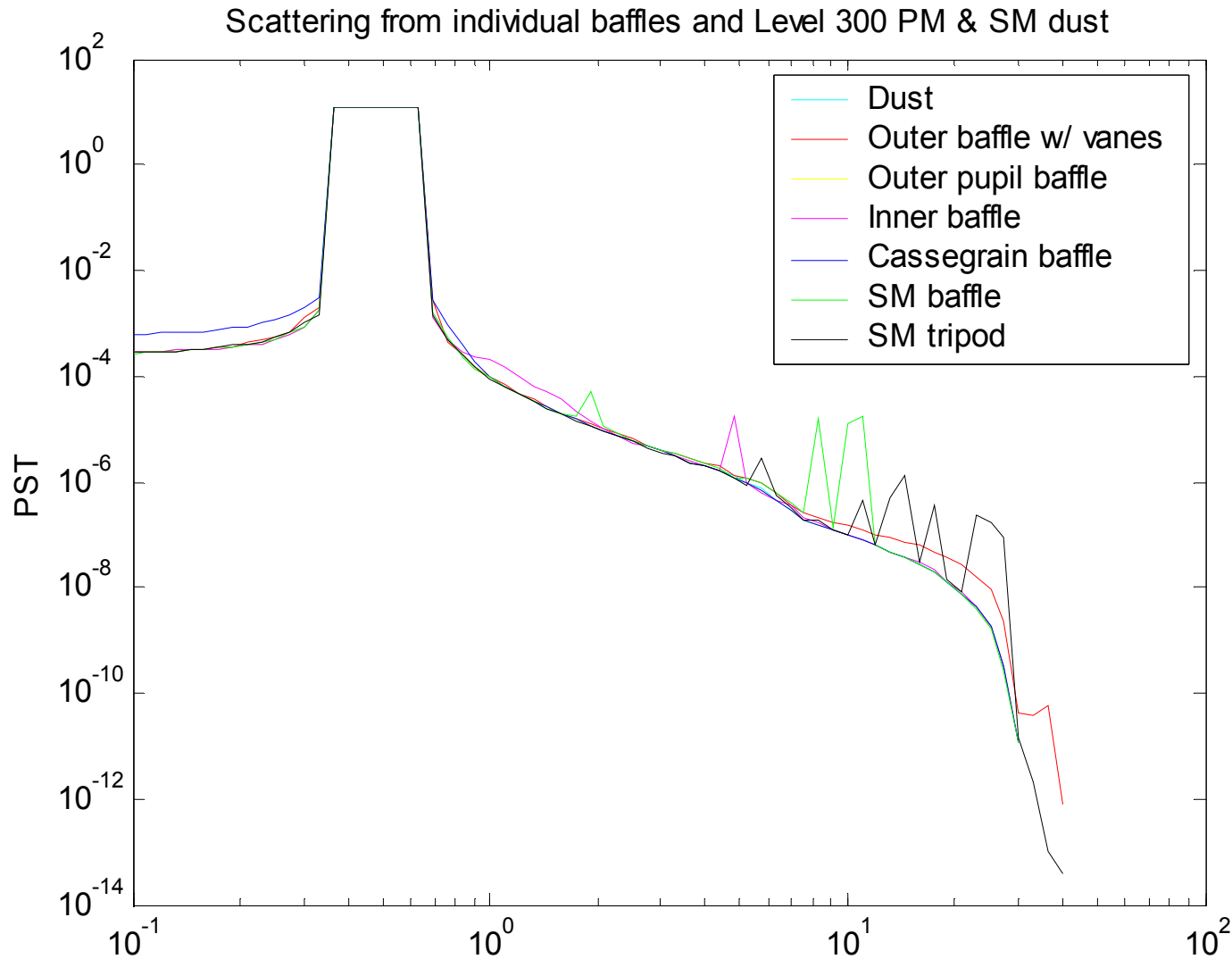
- Effects of dust on PM & SM, various levels
- Integrated with Jelinsky star & galaxy skymap (no Zodi)
 - Level 500: 3.5×10^{-3}
 - Level 400: 1.4×10^{-3}
 - Level 300: 5.9×10^{-4}
 - Level 200: 3.6×10^{-4}
 - Level 100: 3.2×10^{-4}
- Edge of survey region



Scattering from baffles



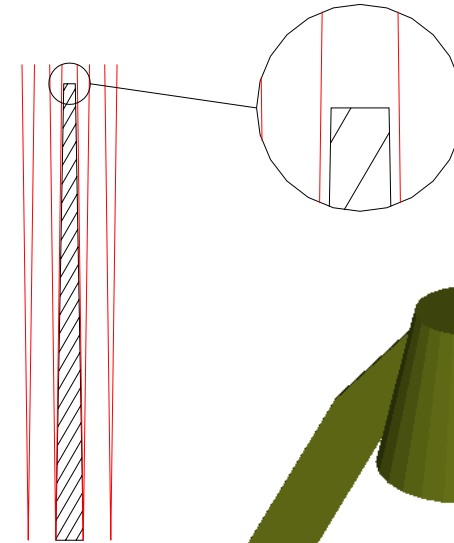
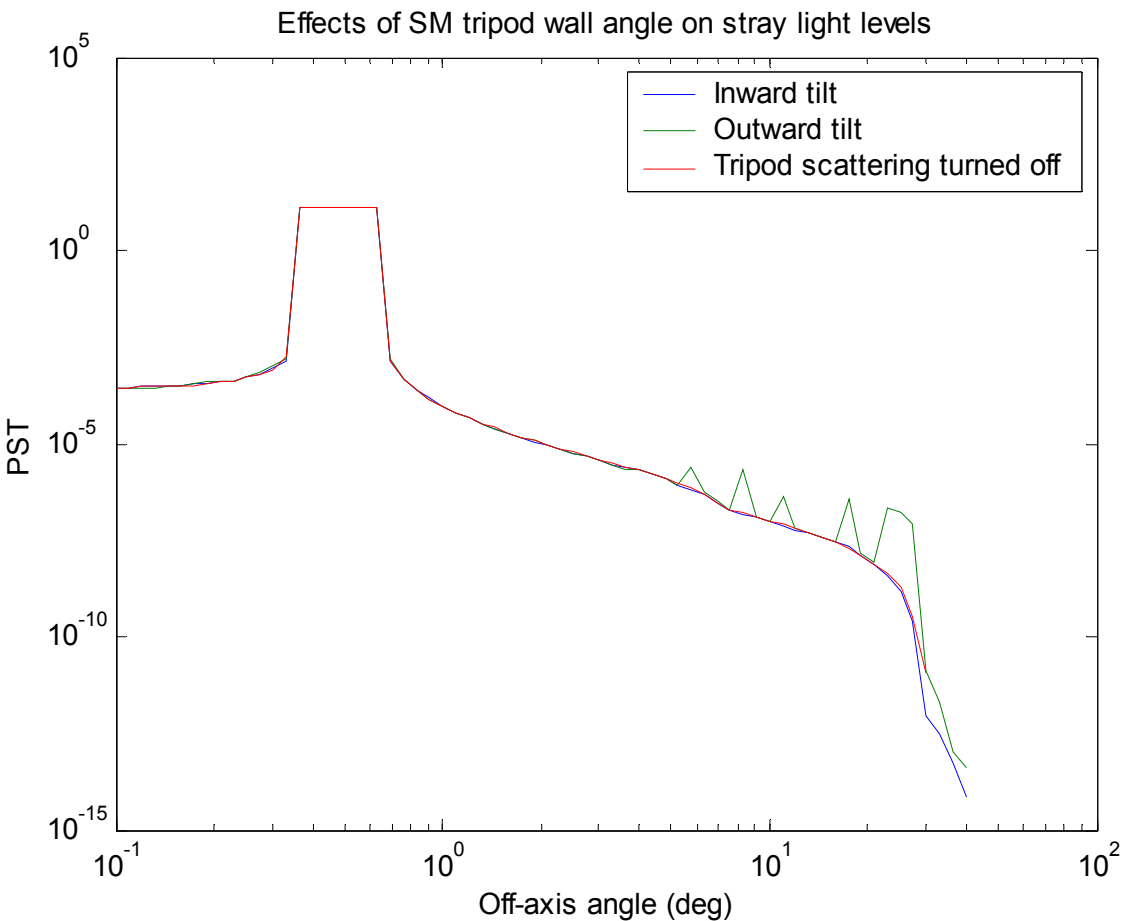
- Stray Light increases at lower latitudes, and when Earth shines in baffle



Secondary Mirror Spider



- Spider vanes angled inward to make invisible to focal plane



- Test runs
 - Z306 Baffle
 - Level 500 contamination on mirrors
 - Regions of interest inside and outside survey region
 - Report photons/s/CCD pixel
 - Interesting locations (Thank you Pat Jelinsky)

location	RA	DEC	Photon rate

-			
North ecliptic pole	+270.0	+66.56	0.0059
South ecliptic pole	+90.0	-66.56	0.0106
SNAP field corner1	+250.39	+57.37	0.0032
SNAP field corner2	+248.64	+58.31	0.0029
SNAP field corner3	+240.57	+53.58	0.0020
SNAP field corner4	+242.06	+52.75	0.0021
Larger SNAP field corner1	+257.88	+57.03	0.0027
Larger SNAP field corner2	+240.05	+57.03	0.0029
Larger SNAP field corner3	+240.05	+55.01	0.0022
Larger SNAP field corner4	+257.88	+55.01	0.0025

- Due to Baffle geometry and observation schedule, Earth occasionally “peeks” into baffle
- P. Jelinsky predicted that this is, worst case, equivalent to a -11th magnitude star (Moon is -6th magnitude)
 - 6th mag. Star: 2.7×10^{15} photons/s/m²
 - $I_{in} * PST * A_{pixel} < 0.001$
 - $2.7 \times 10^{15} * PST * (10 \times 10^{-6})^2 < 0.001$
 - $PST < 3.7 \times 10^{-9}$
 - Could be an issue during targeted observations, depending on season
- In LEO, Molniya or 3-day orbit, equivalent magnitude increases dramatically
- Sun must be blocked by 2 edges, and cannot be allowed to “see” inside baffle

- SNAP Telescope noise floor is in-field Zodiacal radiation
- Goal of stray light design: stray-light \ll Zodi
- Internal field stop and iris limit stray light
- First-order stray light paths identified, and mitigated when possible
- Analyses performed:
 - Thermal emission (via reverse raytrace)
 - Scattered stray light (ASAP, model available on request)
- Excursions into lower Ecliptic latitudes increases Zodi and starlight dramatically (widefield survey)
- In dark Ecliptic polar survey regions, this is $\sim 23^{\text{rd}}$ magnitude per square arcsec \rightarrow within requirements
- In L2 halo orbit, Earth and Moon occasionally illuminate interior of stray light baffle \rightarrow within requirements